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A New Approach to Control A Driven Pendulum with PID Method

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***Abstract* — This paper proposed a PID method to control a driven pendulum. Driven pendulum is a suspended pendulum, which has a motorized propeller at the end of the stick. So it can be controlled with controlling the voltage given to DC motor. The characteristics of the transient response of this system such as overshoots and settling time are not acceptable. For example the settling time of this system is upwards of 10 seconds. The discussed method can improve the time domain performance of the linearized system. The simulation results proven that this method enhanced stability as well as ease of tuning. The presented controller is designed and evaluated using MATLAB/Simulink.**

Keywords- Compound Pendulum; Dirven Pendulum; PID Control; MATLAB/Simlink

I. INTRODUCTION

A simple pendulum system is a mechanical system that exhibits periodic motion. It consists of particle like bob of mass suspended by a light string of length that is fixed at the upper [1]. A Compound Pendulum is a standard topic in most physics courses because it includes some physical subjects such as the simple harmonic motion, the period of oscillation, the acceleration of gravity, the center of mass, the moment of the inertia, momentum, etc. [2].

Literature Works [3]-[5] adopted types of compound Pendulum. This type of pendulum described in this paper has a motorized propeller at the end of the pendulum so it can lift the pendulum after given voltage. This concept of pendulum system is useful and can be applied in real life. This system has many applications such as measurement, scholar tuning, coupled pendulum, entertainment etc.

Controlling this system is important because it enables us to control the pendulum behavior with adjusting the given voltage, such as the stability, rise time, overshoots etc. Kizmaz [6] proposed a sliding mode control for this system and the presented method was based on the improvement of robustness. The SMC controller was designed by changing the control parameters values and reaching the appropriate time domain performance.

A proportional-integral-derivative controller (PID Controller) is a common feedback loop component used for control system. The controller takes a measured value from a process or other apparatus and compares it with a reference set point value. The difference (or “error” signal) is then used to adjust some input to the process in order to bring the process measured value back to its desired set point [7].

In this paper a PID controller was used so the pendulum reaches a steady-state angle with desired transient response and .The presented method is based on the time domain performance of the system.

The contents are organized as follows. Section II describes the driven pendulum and system modeling. Section III proposes a PID control method for this system. In section IV, results of simulation of system with proposed controller. Section V gives the conclusion of this paper.

II. DRIVEN PENDULUM SYSTEM

The schematic picture of the considered pendulum is shown in Fig.1. This pendulum is driven by DC motor. It has a motorized propeller at the end of the stick as was shown in the figure. After applied voltage, the propeller spins and generates torque T to pull up the pendulum.

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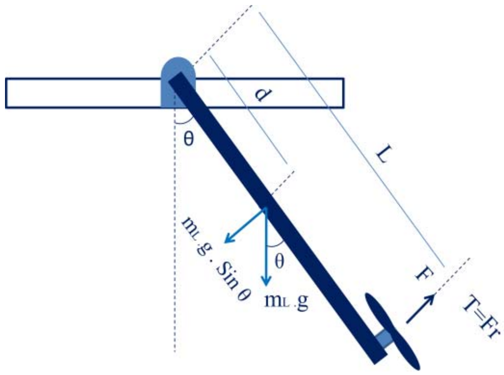

Fig.1. Schematic diagram of driven pendulum

The aim is to command the pendulum to a specified angle. The suspended point is attached to an encoder to provide the measurements of angle and angular velocity of pendulum. It is the most advantages of driven pendulum that enables us controlling its behavior with adjusting the applied voltage. Therefore, the controlled variable for this system, is the angle of the pendulum settled and the manipulated variable is the voltage given to the motorized-propeller.

According to Newton's laws and angular momentum, the motion equation of driven pendulum is derived.

$$J.\ddot{\theta} + c.\dot{\theta} + m_{l.}.g.d.Sin\theta = T \qquad (1)$$

Where;

θ = angular position of the pendulum
$m_{l.}$ = weight of the pendulum
d = the distance between center of mass and pivot point
c = viscous damping coefficient
T = the trust

By considering $Sin\theta \approx \theta$, the linearized motion equation can be written as follows

$$J.\ddot{\theta} + c.\dot{\theta} + m_{l.}.g.d = T \qquad (2)$$

A. Transfer Function

Equation2 gives the transfer function driven pendulum .

$$\frac{\theta(s)}{T(s)} = \frac{1}{J.s^2 + c.s + m_l.g.d} \qquad (3)$$

And the standard representation is

$$\frac{\theta(s)}{T(s)} = \frac{1/J}{s^2 + \frac{c}{J}.s + \frac{m_l.g.d}{J}} \qquad (4)$$

The generated trust T in above equations is not manipulated variable for control system since the pendulum is adjusted by applied voltage.

The transfer function of motorized propeller can be represented as a block diagram.(Fig.2.)

The method to obtain this gain was shown in [6] as

$$K_m = \frac{m_l.g.d.\theta}{V} \qquad (5)$$

Then the block diagram of driven pendulum is given in Fig.3.

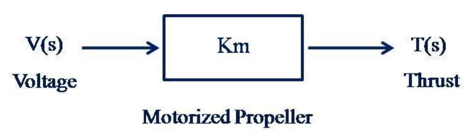

Fig2. Block diagram of Motorized Propeller

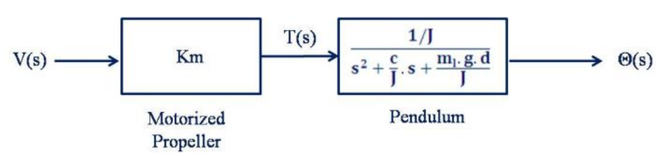

Fig.3. Block diagram of driven pendulum

Moreover, the Transfer function is obtained by

$$\frac{\theta(s)}{V(s)} = \frac{Km/J}{s^2+\frac{c}{J}.s+\frac{m_l.g.d}{J}} \qquad (6)$$

B. State Space

Consider this system represented in state space by

$$x_1 = \theta \quad , x_2 = \dot{\theta}\ , \ x_2 = \dot{x}_1 \qquad (7)$$

is written as

$$\begin{bmatrix} \dot{x_1} \\ \dot{x_2} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -\frac{m_l.g.d}{J} & -\frac{c}{J} \end{bmatrix} . \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{K_m}{J} \end{bmatrix} .u$$

$$Y = \begin{bmatrix} 1 & 0 \end{bmatrix} . \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + 0 \qquad (8)$$

III. CONTROL METHOD

When the characteristics of a plant are not suitable, they can be changed by adding a compensator in the control system. One of the simple and useful compensators feedback control design is described in this section.

In this paper, the control method is designed based on the time-dimension performance specifications of the system, such as settling time, rise time, peak overshoot, and steady state error and so on.

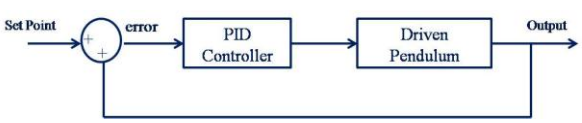

Fig.4. Block diagram of system

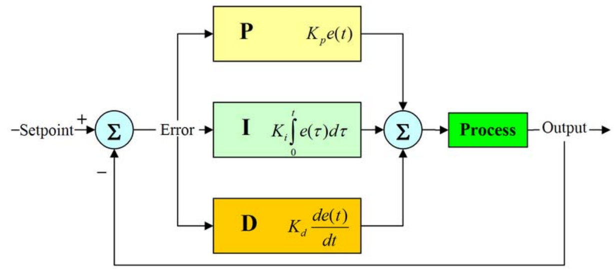

Fig.5. Block diagram of a PID controller [10]

A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs [10].

$$K_d.s + K_p + \frac{K_I}{s} = K_d \frac{s^2+\frac{K_p}{K_d}s+\frac{K_I}{K_d}}{s} \qquad (9)$$

Three parameters must be adjusted in the PID controller K_d , K_p and K_I. In guaranteeing stability and performance and shaping the closed-loop response, it is important to select a suitable compensator.

A. Proportional gain Kp:

Large proportional control can increase response speed and reduce the steady state error, but will lead to oscillation of the system [8].

B. Derivative gain Kd:

The derivative term slows the rate of change of the controller output and this effect is most noticeable close to the controller set point. Hence, derivative control is used to reduce the magnitude of the overshoot produced by the integral component and improve the combined controller-process stability [10].

C. Integral gain KI:

Integral control is favorable for diminishing the steady state error but it will lengthen the transient response [8].

This paper attempts to design optimal values for controller parameters. Then it obtained the value of PID gains by Ziegler and Nichols method [9]. Ziegler and Nichols provided a technique for selecting the PID gains that works for a large class of industrial systems. These equations can be written as

$$k_p = 0.6K_m, \quad k_d = \frac{k_p \pi}{4\omega_m}, \quad k_i = \frac{k_p \omega_m}{\pi} \tag{10}$$

IV. SIMULATION

A. Simulation Method

After the mathematical model of system obtained, control system designed. Then MATLAB/Simulink was used to done the simulation of system behavior.

The model parameters are based on an experimental set up previously by [6].

Where;

d = 0.03 m, $m_{pl} = 0.36$ kg , g = 9.8 m/sn^2 ,
J = 0.0106 Kgm^2 , c = 0.0076 Nms/rad ,
Km = 0.0296

Therefore, the transfer function is given by

$$\frac{\theta(s)}{V(s)} = \frac{2.7922}{s^2+0.7191s+9.9989} \tag{11}$$

According to equation (10) , Values of PID gains was computed as follows

$$K_p = 2.2 \quad K_d = 1.1 \quad K_I = 0.1$$

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B. Simulation Result

The open loop response is given in Fig.7. It illustrates the need for control. The settling time of the system is upwards of 10 seconds. The reason for the persistent oscillations is a lack of damping in the system.

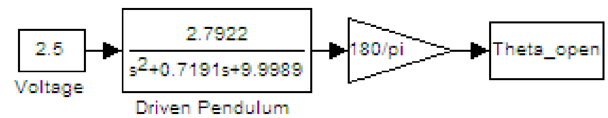

Fig.6. Open Loop system modelling in Simulink

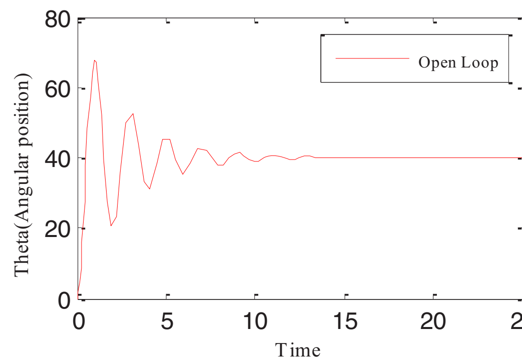

Fig. 7. Open Loop Respons

First, the open loop system is modeled in Simulink as shown in Fig.6. Then for investigate the capacity of controller, the system consists of driven pendulum and PID controller was simulated (Fig.7.). In this simulation, the aim is to command the pendulum to settle at 40 degrees angle.

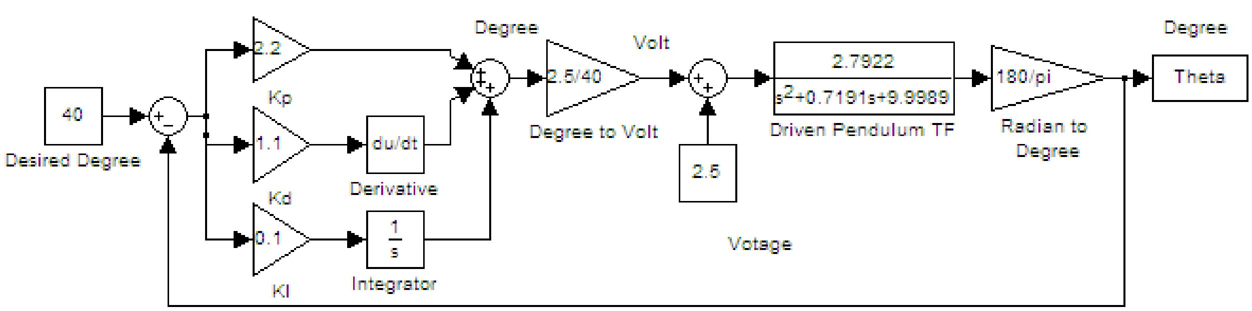

Fig.8. Simulinke Model of Driven Pendulum with PID controller

The response of driven pendulum with PID controller is shown in Fig.8.From figure the rise time and settling time decreased with control system. In addition, output of the system reaches the desired value without overshoot. Results illustrate the fact that simulation response curves are in good agreement.

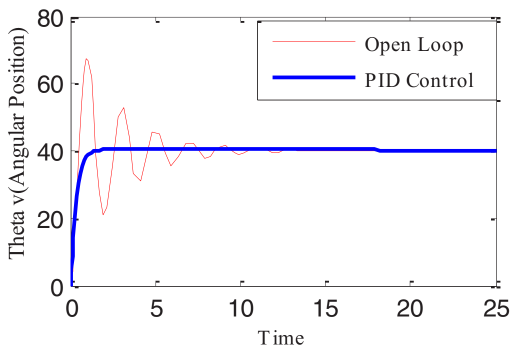

Fig. 9. System Response with and without Controller

V. Conclusoin

In this study, a PID controller was designed for a linearized driven pendulum system. The simulation was done for the system with and without controller. The Response characteristics of driven pendulum improved with PID control. The optimal values for controller parameters are obtained by Ziegler and Nichols method. The simulation results proven that the PID control method compared to sliding mode controller, which designed by changing control parameter values [6], is an easy-tuning and more effective way to enhance stability of time domain performance of the driven pendulum system.

Various control methods can be designed for driven pendulum such as Fuzzy control, Fuzzy PID control, MRAC, etc.

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